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CO_2 Cryogenic Liquid Flow Impact on Annular Baffles of Lorry Tanker during Braking

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Abstract

The relative motion of cryogenic liquid produces strong impact on tanker structure due to the lorry's acceleration, deceleration, braking and turning. This liquid slashing problem is a dynamic and periodic interaction with fluid structure that reduces movement stability of lorry and its long term service leads baffle and tanker to fatigue fracture. This dynamic and periodic effect leads the baffle and tanker to failure caused by fatigue fracture. So it is of great importance to investigate and minimize the baffle's stress and strain to reduce the fatigue fracture effect. The present work is based on one tanker with effective volume 23.6 m^3 for 23630 kg CO_2 at designed condition of 2.25 MPa and -40 ℃. Two different kinds of typical baffle configuration: annular and chord plate are provided in the same tanker to simulate the liquid flow with time in certain motion mode by CFD. During the early half braking process, the annular baffle distributes fluids into the whole room of the tanker, while the chord plate drives liquid into the lower part of the tanker in the direction of liquid height. The maximum fluid velocity for the annular baffle is 4.70 m/s, less than 4.93 m/s that for chord plate. In this situation, the stress the former suffers is greater than that the latter. Then applied force on the different baffle structures with time is obtained.

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Keywords: fluid structure interaction; fatigue fracture; annular baffle; chord plates

1. Introduction

The relative motion of cryogenic liquid produces strong impact on tanker structure due to the lorry's acceleration, deceleration, brake and turning[1]. This liquid slashing problem is a dynamic and periodic fluid structure interaction

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that reduces movement stability of lorry and its long term service leads baffle and tanker to fatigue fracture[2]. The dynamic stability of liquid gas tankers and ship cargo tankers, and liquid hydrodynamic impact loading are problems of current interest to the designers of such systems[3]. It is of great importance to investigate and minimize the baffle's stress and strain.

The objective (shown in Fig. 1) is a special CO_2 Cryogenic Liquid Lorry Tanker manufactured by Zhangjiagang CIMC Sanctum Cryogenic Equipment Co., Ltd. The polyurethane foaming thermal insulation and perlite powder vacuum insulation are employed for the tank. At designed condition of 2.25 MPa and -40 ℃, it has a named effective volume 23.6 m^3, 23630 kg liquid CO_2.

Fig. 1. LCO_2 Cryogenic Liquid Tanker.

The obstacle structure in the tank is designed to slow down the fluid flow effectively and reduce instantaneous impact force on the header and tank. Its shape and location is very important. The present work is to compare its arc baffle configuration (shown in Fig. 2(a)) with common double chord plate configuration (shown in Fig. 2(b)) in the same tank and operating condition.

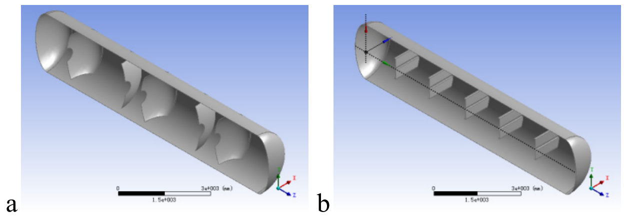

Fig. 2. baffle configuration: (a) annular baffle; (b) chord plate.

2. Mesh data and boundary conditions

2.1. Single layer mesh

A better mesh quality guarantees a more accurate solution. For improving the mesh quality for accurate solution, the method with only single layer mesh in the normal direction was employed to reduce the computational scale and refine the mesh at certain areas of the tank geometry. It is important to compromise the required accuracy and CPU time.

Fig. 3. mesh for annular baffle (up) and chord plate (down).

2.2. Fluid material

The density of carbon dioxide at designed condition of 2.25 MPa and -40 ℃ is 1120 kg/m^3 according to Span, R., & Wagner, W.[4]. The vapor phase in the tank exists with the density being 59.56 kg/m^3 because of the leak heat from the ambient. G.R. Somayajulu[5] developed a correlation to provide the surface tension at the liquid-vapor interface of a saturated carbon dioxide fluid. This correlation requires only one argument, in addition to the fluid name, and that is the temperature. That is, it is insensitive to pressure. Therefore, a value of 0.01217 N/m was adopt for the liquid-vapor interface of a saturated carbon dioxide fluid according to the operating temperature -40 ℃.

2.3. Multiphase model and turbulence model

A homogeneous multiphase model with the free surface was used for this simulation because the gas and liquid phase carbon dioxide will maintain a well-defined interface. Appropriate boundary conditions are necessary for a free surface simulation because free surface simulations are more sensitive to incorrect boundary and initial guess settings than other more basic models. The turbulence model is the common k- ε and the corresponding scalable wall function.

2.4. Braking process

The braking process is a transient dynamic simulation of two-phase liquid sloshing by the inertia load. For automobile tanker, tank container, tube trailers and bundle type containers, etc., the inertia force load in movement direction should be converted into an equivalent static force of 2 times the maximum weight; according to the paragraph 3.10.1.1 in TSG R0005-2011[6]. The initiate velocity is 22 m/s (79.2 km/h) and the deceleration is g, 2g, that is 9.8 m/s^2, 19.6 m/s^2, respectively. The tank takes 2.24 s, 1.12 s and 24.69 m, 12.35 m to stop. The fluid distribution and flow in the tank is complex and time dependent when the tanker slows down.

2.5. Initial condition

The filling volume of fluid was defined in terms of the rate of gas phase volume to the whole tank. The maximum allowable filling volume should be less than 95% of the tank volume according to the paragraph 3.10.7 in TSG R0005-2011.

3. Computational result and analysis

The density of liquid carbon dioxide is 1120 kg/m^3, about 10 times of that of gas in the designed pressure and temperature. So the tank suffers mainly from the liquid impact by the effect of inertia load.

The inertial load exerted by the fluid is time-dependent and can be greater than the load exerted by a solid of the same mass. The fluid initially keeps relative static for the tank wall when t=0s, and moves quickly with the tank begins to decelerate at 19.6 m/s2. Fig. 4 gives out the liquid phase distribution for annular baffle and chord plate during braking process, the annular baffle distributes fluids into the whole room of the tanker at early half process, while the chord plate drives liquid into the lower part of the tanker in the direction of liquid height. In this situation, the stress the former suffers is greater than that the latter suffers. After the tank stops, the fluid continues to slosh. Motion of a fluid can persist beyond application of a direct load to the container.

Fluid sloshing in the tank may be restrained or controlled by baffles with certain configuration at the right position, and the effectiveness is highly subject to the shape, the location, and the number of baffles inside a tank. Fig. 5 gives out the liquid phase velocity distribution for annular baffle and chord plate during braking. The maximum fluid velocity for the annular baffle is 4.70 m/s, less than 4.93 m/s that for chord plate. The amplitude of liquid slosh depends on the amplitude and frequency of the tank motion, liquid-fill depth, liquid properties and tank geometry.

During the brake process, the baffles damps the fluid sloshing and suffers forces in different direction. The force in X component also in accordance with the motion is 103 larger than the other in Y and Z component, therefore it is taken into consideration. Fig. 6 gives out the applied force on the different baffle structures with time, and obviously the force of the annular baffle is lower than that of the chord plate in the most operating condition points. The result show that the stress and strain generated in the annular baffle is less than that in the chord plates. So the fatigue fracture resistant of tanker with annular baffle is superior to the configuration with chord plate from the prospective of stress and strain.

4. Conclusion

The baffle structure in the tank is designed to slow down the fluid flow effectively and reduce instantaneous impact force on the header and tank. The present work is to compare its arc baffle configuration with common chord plate configuration in the same tank and operating condition. During the early half braking process, the annular baffle distributes fluids into the whole space of the tanker, while the chord plate drives liquid into the lower part of the tanker in the direction of liquid height. In this situation, the stress the former suffers is greater than that the latter. The maximum fluid velocity for the annular baffle is 4.70 m/s, less than 4.93 m/s that for chord plate. Its shape and location is very important. The amplitude of liquid slosh depends on the amplitude and frequency of the tank motion, liquid-fill depth, liquid properties and tank geometry.

Acknowledgments

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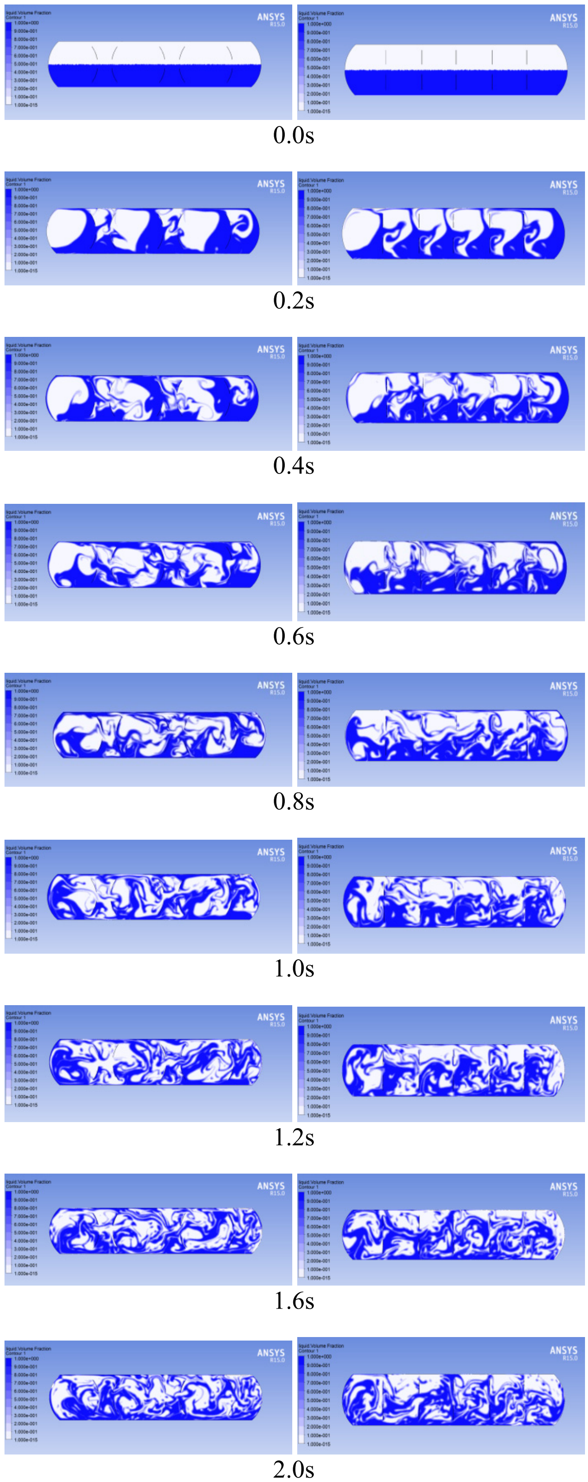

Fig. 4. liquid phase distribution for annular baffle (left) and chord plate (right) during braking.

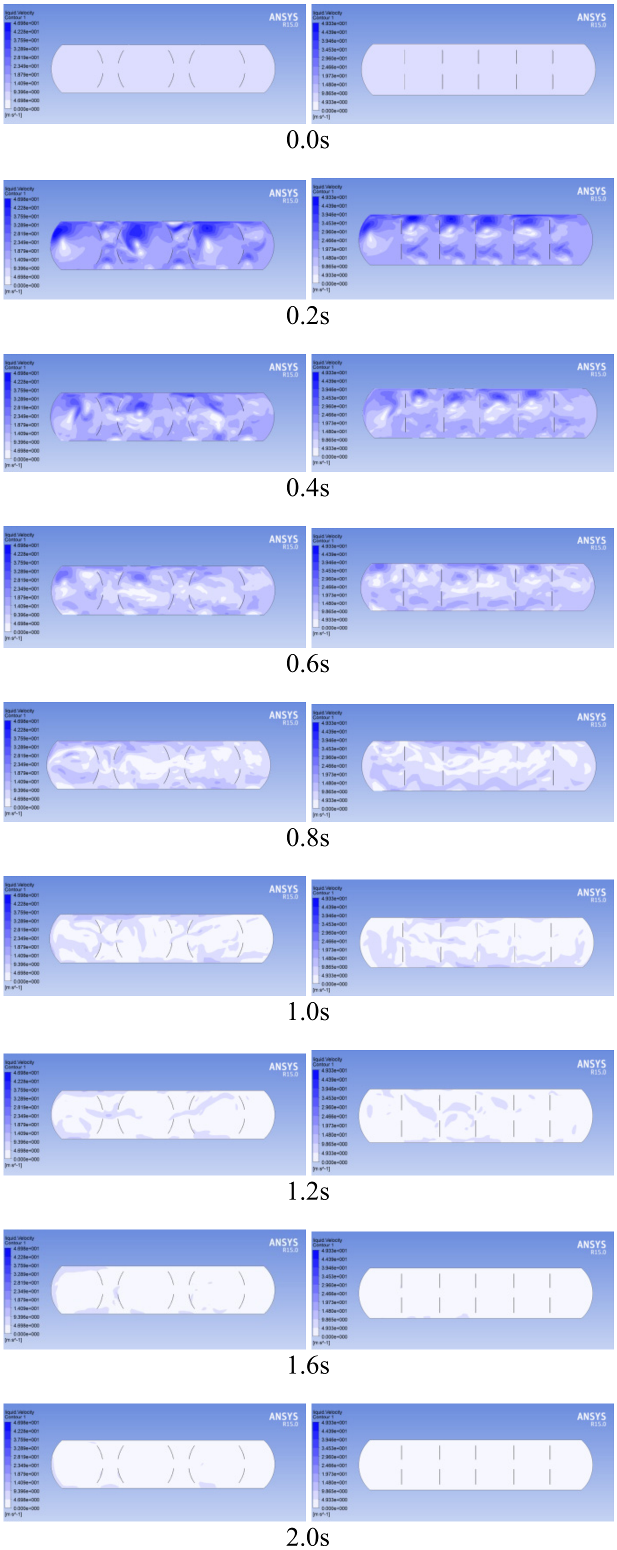

Fig. 5. liquid phase velocity for annular baffle (left) and chord plate (right) during braking.

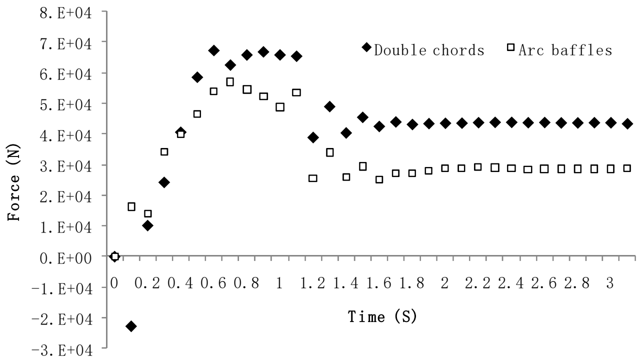

Fig. 6. applied forces on the different baffle structures with time.

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